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Microwave 대역에서의 고온 및 고출력용 GaN MESFET 소자에 관한 연구

Investigation of Microwave GaN MESFETs for High-Power and High-Temperature Application

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Abstract : In this report, the large-signal RF performance of GaN MESFETs at different operating temperatures is investigated using a harmonic balance modeling technique. The predicted device performance calculated by the large-signal model of a GaN FET is shown to be in good agreement with experimental data. It is demonstrated that the optimal RF performance of a GaN MESFET amplifier is achieved by balancing the input impedence for a optimized design. A GaN MESFET with the optimized design is predicted to produce maximum RF output power of about 4 W/mm and 1 W/mm at room temperature and 773 K, respectively. The device produces a peak Power-Added Efficiency (PAE) of 52 % and 32 % at the two temperatures.

1. Introduction

Wide Band-gap semiconductors are of interest for high-temperature and high-power applications from dc into the microwave range. This interest stems primarily from the high thermal conductivity and high peak electric field at breakdown inherent in wide band-gap materials. In addition, the chemical inertness in wide band-gap materials would allow the devices fabricated from these materials to operate in chemically hostile environment.

In particular, GaN possesses desirable material characteristics for electronic devices along with its great potential for optical devices throughout the entire visible spectrum and extending far into the UV. The theoretical low-field electron mobility of GaN is about 1000 $cm^2/V\ s$ which is higher than the value for any of the SiC polytypes. GaN films with very high breakdown voltage have been already demonstrated. It is expected that the power losses of GaN devices will be lower than those in SiC devices at both high and low frequency operation.

Despite the excellent potential of GaN MESFET, however, there has not been enough data on the microwave large-signal performance of devices fabricated from the material. In this paper, therefore, the RF operational potential of M

ESFET's fabricated from GaN is investigated using a harmonic balance device/circuit model.

2. Model Verification

In this work, an advanced physics based MESFET model is employed to investigate the large-signal microwave performance of GaN MESFET. The model describes the conduction and displacement current of the transistor as a function of instantaneous terminal voltages and their time derivatives. The large-signal performance of the circuit which consists of intrinsic time-domained FET and extrinsic frequency-domained parastic elements. The large-signal performance of the circuit is calculated based on the device design, material parameters, and circuit elements. The more details can be found elsewhere. To investigate the microwave performance of GaN MESFETs the large-signal model was calibrated to experimental device structure. Device fabrication process and device structure is found in other references. Several material parameters published were obtained and used for the calculation. Fig.1 compares the well matched calculated and experimental dc I-V characteristics. The model also accurately predicted the experimentally measured small-signal power gain as is shown in Fig.2. The maximum frequency (f_{max}) of the device is found out to be about 35 GHz. The large-signal RF performance of the device degrades as the operating frequency is increased. For example, the Power-Added Efficiency(PAE) of the device was predicted to be about 20 % at an operating frequency of 14 GHz and about 31 % at 5 GHz.

3. Potential of a GaN MESFET

The potential large-signal performance of GaN MESFET was evaluated after the device structure was optimized followed by the optimal input impedence matching. The optimal conducting channel design was determined by changing the doping concentration in the range 2 x 10^{17}/cm^3 to 4 x 10^{17}/cm^3 and the channel thickness in the range 0.1 to 0.2 μ m. The temperature dependence of electron mobility can be expressed as $\mu \propto T^{-1.9}$. The dc-IV characteristics of an optimized GaN MESFET at 300 K is shown in Fig. 3. The device exhibits a peak drain current of 500 mA. Fig. 4 and Fig. 5 show the large-signal RF performance of the optimised device at operating temperatures of 300 K and 773 K. The device was biased for class A operation at 8 GHz with a drain voltage of V_{ds} = 40 V.

4. Tuning Issue in RF Operation of GaN MESFET

Simple analysis of MESFET dc I-V characteristics would suggest that the optimal load impedence for am amplifier can be estimated by observing the maximum drain current and drain breakdown voltage. Ideally, maximum output power of a class A amplifier should be obtained by promoting the maximum peak to peak swing of the drain voltage and current. Fig. 6 compares the dynamic load line of the optimized GaN MESFET for 0 dB and 3 dB gain compression power level. As the device is driven into large-signal operation(at 3 dB gain compression), the load line shifts to a slightly higher operating bias current. The load line encounters the forward gate conduction regions of the RF I-V plane. The calculated time domain waveforms for the device biased at 40 V at the 0 dB and 3 dB gain compression are shown in Fig. 7 and Fig. 8. At the 3 dB compression power level the drain voltage waveform is entering into the forward gate conduction region. Fig. 8 demonstrates that the higher drain bias causes the average drain current to increase. Fig. 9 and Fig. 10 show the time dependent drain voltage and drain current, respectively showing the waveforms operating at 52 % and 18 %. The performance variation between the two cases is primarily due to the difference in impedence matching. The load line for the device at the 18 % and 52 % peak PAE operating power levels is show n in Fig. 11. Examnination of the two operating RF I-V characteristics indicates that the load line for 52 % peak PAE, compared with that for 18 % peak PAE, is caused by the optimal input impedence matching which results in the maximum peak to peak swing of the drain current and voltage. The poor impedence matching leading to 18 % peak PAE causes poor performance RF characteristics such as output power and power gain as is shown in Fig. 12.

5. Conclusion

The large-signal operating principles of GaN MESFET amplifiers are investigated. The calculated large-signal RF performance is shown to be well matching with experimental results. The great potential of GaN MESFET for high-power, high-temperature application is demonstrated with the help of optimization of device design along with optimal input impedence matching process.

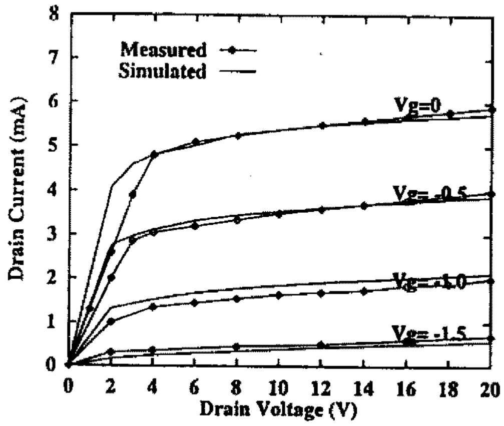

Fig. 1: dc I-V characteristics of a GaN FET

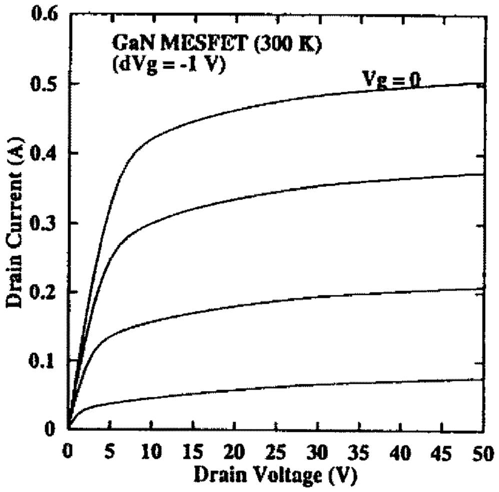

Fig. 3: dc I-V plot of optimized GaN MESFET

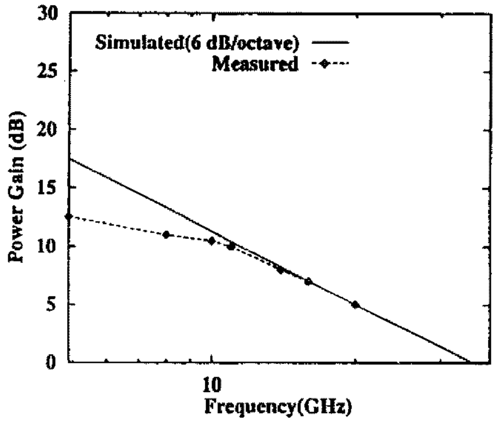

Fig. 2: Small-signal power gain of a GaN FET

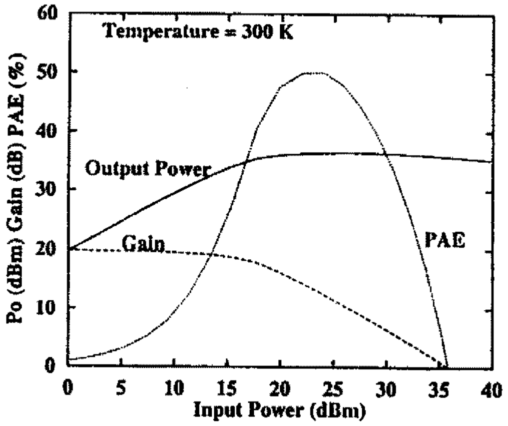

Fig. 4: Large-signal data of a GaN MESFET(300 K)

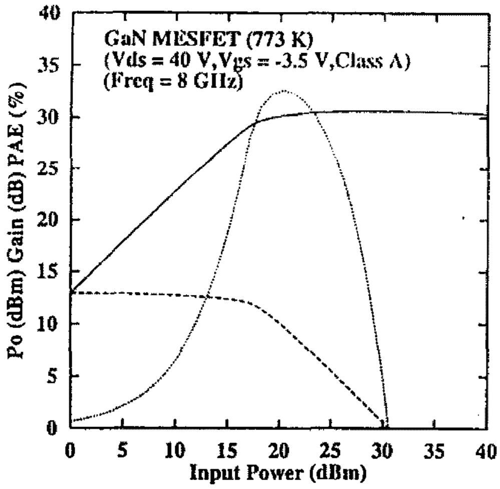

Fig. 5: Large-signal data of a GaN MESFET(773 K)

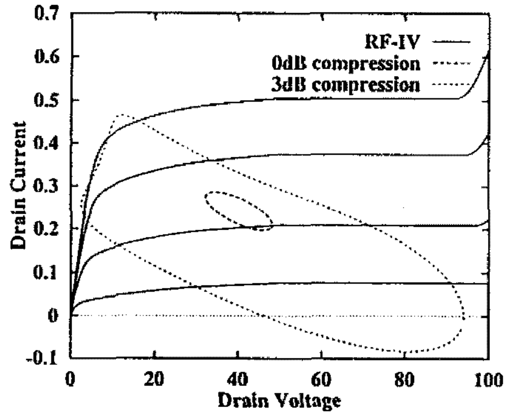

Fig. 6: Dynamic load line for different compressions

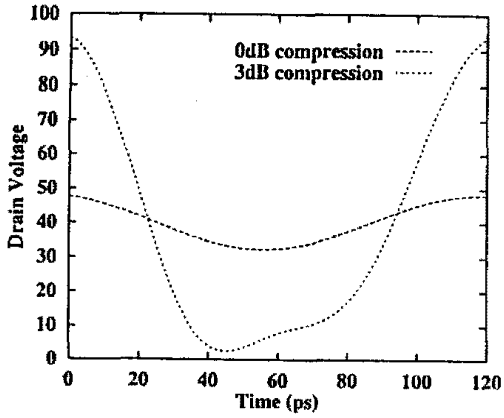

Fig. 7: Drain voltage vs Time(comp.)

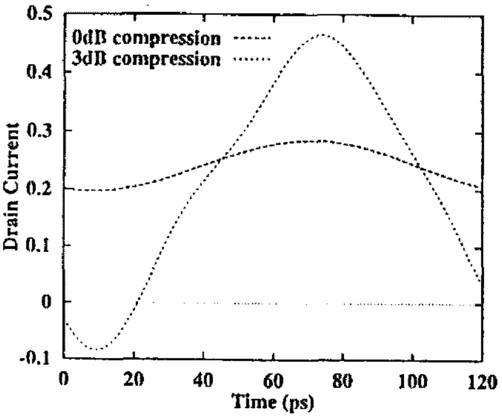

Fig. 8: Drain current vs Time(comp.)

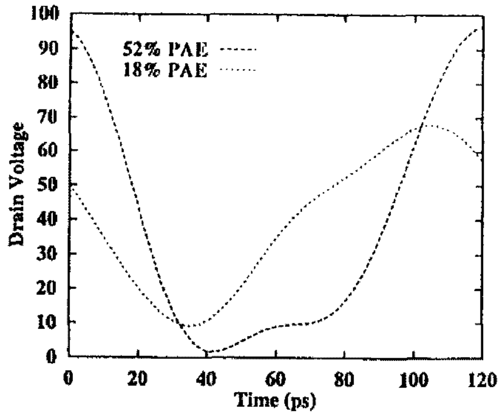

Fig. 9: Drain voltage vs Time(PAE)

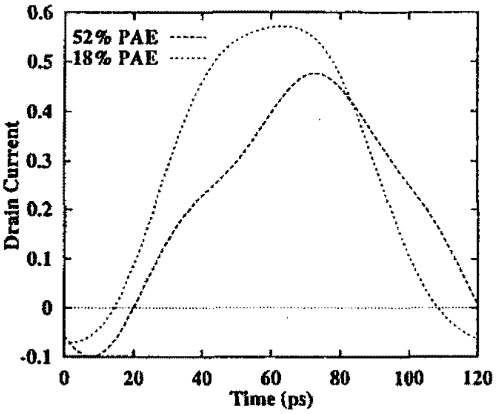

Fig. 10: Drain current vs Time(PAE)

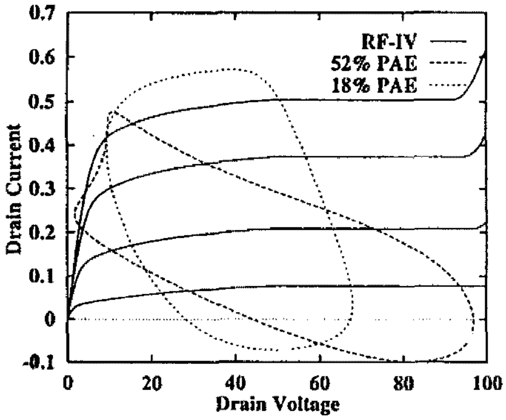

Fig. 11: Dynamic load line for different PAE

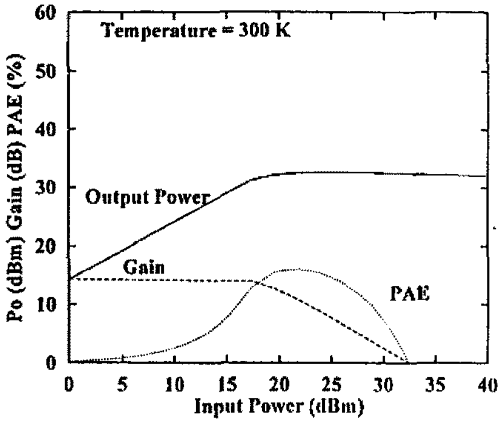

Fig. 12: Large-signal data for PAE=18 %